JPL D-20327

Mars Reconnaissance Orbiter Project Mission Assurance Plan

Version 1.0

Document Custodian:
Phillip R. Barela

April 7, 2001

Jet Propulsion Laboratory
California Institute of Technology

April 7, 2001

Mars Reconnaissance Orbiter Project

Mission Assurance Plan

Document Custodian:

PRBarela

Phillip R. Barela
Mission Assurance Manger

Approved:

Benhan Jai
Mission Operations System Manager

Howard Jay Eisen

Howard J. Eisen
Spacecraft Manager

4/17/01

William H. Mateer II
Deputy Payload Manager

4/17/01

James E. Graf
Project Manager

TABLE OF CONTENTS

SECTION 1
INTRODUCTION

1.1 PURPOSE

The purpose of this document is to define the mission assurance program to be applied to the development of the Mars Reconnaissance Orbiter (MRO).

1.2 SCOPE

The mission assurance program identifies requirements and activities which apply to all MRO team members. Each organization providing a flight system shall create specific discipline assurance plans that will define in more detail the assurance programs to be employed at their respective organizations during the flight equipment development process. Utilization of existing documentation, processes, and procedures are recommended.

1.3 APPLICABLE DOCUMENTS

The following documents of the issue in effect on date of invitation for bids, or request for proposal, or product manufacture, form a part of this document to the extent specified herein. In case of conflict, this document shall take precedence. JPL-approved contractor equivalent documents are allowable and encouraged.

All materials and processes used for applications including structural members, mechanical parts, packaging, cabling, and fasteners for the

fabrication of flight hardware are covered by this document. These requirements are generally applicable to both orbiter and instruments. Contractors and their subcontractors have the option of using their own materials and processes requirements documents, but prior JPL approval of such documents is required. All the requirements contained in this document shall apply to both JPL and its contractors, and shall be identified in appropriate contractual documentation

In cases of conflict between this document and any of the applicable documents listed below, this document shall take precedence.

1.3.1 JPL Documents

900-434	Environmental Testing Facilities and Practices Standard
CS515574	General Specification for Hybrid Integrated Circuit Crystal Oscillator (Rev E)
FS 511316	Detail Specifications for Qualification of Critical Fasteners
JPL STD-00009	Flight Materials/Process/Fasteners/Pkging/Cabling H/W Selection Guide
JPL D-560	JPL Flight Systems Safety Requirements (601-4)
JPL D-1348	JPL Standard for Electrostatic Discharge Control
JPL D-5703	JPL Reliability Analysis Handbook

JPL D-8091	JPL Standard, Problem Failure Reporting System, Guidelines and Procedures
JPL D-8545, Rev B	JPL Derating Guidelines (Rev B)
JPL D-15378	JPL Software Development Process Description
JPL D-17868	JPL Design, Verification/Validation and Operations Principles for Flight Systems
JPL D-18002	Radiation Test Requirements for Ionization and Displacement Damage
JPL D-TBD	MRO Configuration Management Plan
JPL D-TBD	MRO Risk Management Plan
JPL D-TBD	MRO Software Management Plan
JPL D-20329	MRO Project Safety Plan
JPL D-20241	MRO Preliminary Environmental Requirements & Estimates
QAP 44.10	Receiving Inspection and Identification of Flight Bulk Materials
SPI-4-11-8	Selection of Threaded Fasteners for Flight Applications

1.3.2 NASA and Military Documents

EWR 127-1	Range Safety Manual
JSC SP-R-0022A	Vacuum Stability Requirements of Polymeric Materials For Spacecraft Applications
MIL-C-39010	Coil, radio frequency, fixed, molded, established reliability general specification for
MIL-I-6870	Inspection program requirements, nondestructive for aircraft and missile materials and parts
MIL-PRF-123	General Specification for Capacitors, Fixed, Ceramic Dielectric
MIL-PRF-19500	General Performance Specification for Semiconductor Devices
MIL-PRF-38534	General Performance Specification for Hybrid Microcircuits
MIL-PRF-38535	General Performance Specification for Manufacturing Integrated Circuits
MIL-STD-462	Electromagnetic interference characteristics, measurement of
MIL-STD-883	Test Methods and Procedures for Microelectronics
MIL-STD-1595	Qualification of aircraft, missile and aerospace fusion welders
MIL-STD-1246	Product cleanliness levels and contamination control program
MSFC-HDBK-527/ JSC 09604	Materials Selection List for Space Hardware Systems
MSFC-SPEC-522	Design Criteria For Controlling Stress Corrosion Cracking
NASA-STD-5003	Fracture Control Requirements for Payloads Using the Space Shuttle
NASA-STD-6001	Flammability, Odor, Offgassing and Compatibility Requirements and Test Procedures for Materials in Environments That Support Combustion

QML-38534	Qualified Manufacturers List of Custom Hybrid Microcircuits Qualified Under Military Specification MIL-PRF-38534
QML-38535	Qualified Manufacturers List of Microcircuits Manufactured to the Requirements of MIL-PRF-38535 (including Appendix A where applicable)
QPL-19500	Qualified Products List of Products Qualified under MIL-PRF-19500, General Specification for Semiconductor Devices
SSQ25000	Destructive Physical Analysis Testing Specification for the Space Station Program, Revision B

1.3.3 Other Documents

ISO 14644	Cleanrooms and Associated Controlled Environments
MIL-HDBK-5	Metallic Materials and Elements for Aerospace Vehicle Structures
MIL-HDBK-17 (Volumes 1-3)	Plastics for Aerospace Vehicles
MIL-HDBK-6870	Inspection Program Requirements Nondestructive for Aircraft and Missile Materials and Parts
MIL-STD-810	Environmental Engineering Considerations and Laboratory Tests
MIL-STD*-889	Dissimilar Metals
MIL-STD-1595	Aerospace Welder Performance Qualification
ASTM-E595	Detail Specification for Vacuum Outgassing of Polymers
ASTM-E1417	Standard Practice for Liquid Penetrant Examination

1.4 OBJECTIVE

The objective of the MRO mission assurance program is to identify, control, mitigate, and communicate Project risks/problems in a manner that is consistent with Project resources (e.g. funding, mass, power, risk, etc.).

1.5 ROLES AND RESPONSIBILITIES

Team members are responsible for the development, control, and implementation of the Mission assurance program at their organizations. Team members are also responsible for communicating their mission assurance plans, implementation status, concerns, and issues to the MRO Project Office. As issues/problems/failures arise, risk (programmatic/mission) mitigation actions are the responsibility of the team members organization that has the issue/problem/failure. Where issues/problems/failures and resulting mitigation actions, cross team member interfaces the impacted team member(s) and the MRO Project Office shall be informed in a timely manner. The objective of the mitigation effort shall be focused on minimizing impacts to the MRO Project as a whole. In addition to the internal communications, discussed above, the MRO mission assurance team, with the project office, is responsible for communication with the National Aeronautics and Space Administration (NASA) on all aspects of the mission assurance program. These communications will take the form of the mission assurance teams participation in periodic Project reviews, as well as other less formal means.

The MRO Mission Assurance Manager (MAM), as a member of the MRO Project staff, reports to the Project Manager and the independent Jet Propulsion Laboratory (JPL) Safety and Mission Assurance Directorate on all aspects of the mission assurance program and implementation status. In addition the MRO MAM is responsible for the coordination of Mission Assurances tasks between team organizations, including the elements described in this plan, and risk management. In particular the MAM will provide Project level perspective/commonality support for electronic parts, quality assurance, environmental requirements, materials and processes, configuration management, risk management, reliability and safety.

The MAM is responsible for acquiring insight into the planning and implementation of Mission Assurance throughout the MRO Project. In support of this responsibility team members shall provide access to documentation and information of analyses, test reports, failure reports, and other documents as requested by the MAM.

SECTION 2
RELIABILITY ENGINEERING

2.1 RELIABILITY ASSURANCE

2.1.1 Objectives

The objectives of this section are to identify the reliability tasks and activities necessary to accomplish the mission goals. To this end, the following specific objectives apply:

a. Assure that adequate consideration is given to reliability during the design and development of the hardware.
b. Assure that possible sources of high risk are identified and where possible eliminated through the design verification & validation process.
c. Assure that hardware reliability activities are implemented in a timely manner consistent with Project schedules.
d. Assure that related policies are translated into working level reliability assurance requirements that are implemented consistently throughout the Project.
e. Assure the Project is aware of any areas of potential high risk and residual risk.

2.1.2 Responsibilities

Primary responsibility for the implementation and accomplishment of activities that satisfy the requirements of this section belongs to the JPL responsible design agencies and their respective contractors and subcontractors. All hardware developers shall extend these requirements to their subcontractors and suppliers through appropriate contractual documentation. Any deviation from these requirements must be waived in accordance with the MRO Configuration Management Plan.

2.1.3 Reliability Assurance Requirements

Analyses of the hardware design shall be performed to ensure proper built-in reliability and consistency with mission requirements and objectives. The analyses shall be performed concurrently with the design effort. The following reliability analyses shall be performed consistent with the intent of JPL D-5703, “Reliability Analyses Handbook.”

a. System/Mission Fault Tree Analysis
b. Failure Modes, Effects, and Criticality Analysis (FMECA)
c. Mechanical/Electromechanical Fault Tree Analysis (FTA)
d. Worst Case Circuit Analysis (WCA)
e. Electrical Parts Stress Analysis (E-PSA)
f. Power Supply Transient Analysis
g. Thermal Stress Analysis
h. Structural Stress Analysis

i. Single Event Effect Analysis (SEE)

Responsible design agencies within JPL, as well as in contractor and subcontractor organizations, shall be responsible for performing, documenting, and updating all of their analyses. Analysis documentation shall include relevant backup data such as circuit description, schematics, functional or logical block diagrams, functional I/F requirements, parts lists, results summary and conclusions. Analysis documentation guidelines are outlined in JPL D-5703. All analyses shall be maintained in a current state and reflect the currently approved design. The design agencies shall take appropriate actions driven by the results of each analysis.

For inherited hardware, existing analyses may be satisfactory if applicability is demonstrated by verification that all originally applied requirements, environments, and other bounding conditions envelope the corresponding elements required by the current application and if the analyses were adequately performed to these conditions. Analyses shall be performed and documented, if applicability cannot be demonstrated or the analysis is not available.

The entire Problem/Failure Report file against inherited designs and hardware by serial number, plus a list of the reports considered by cognizant personnel to be applicable to the current status of the hardware/design, shall be made available for Project review. Open and Red Flag [or contractor Red Flag equivalent] reports against this hardware shall be reviewed and either closed in accordance with the requirements of MRO Project Problem/Failure Reporting requirements or accepted by the technical manager as documented by an approved waiver. All closed reports shall be reviewed to verify the appropriateness of the closeout, and to identify known residual risks (i.e., Red Flag equivalent reports) associated with the inherited design/hardware. Some reports may be reopened for further work.

All analyses shall be completed and reviewed by the subsystem CDR for the equipment being analyzed.

2.1.4 Reliability Design Requirements

The following sections define the individual analysis requirements. Mission and environmental factors (such as life, temperatures, radiation, etc.) used in the following analyses are based upon values defined in "MRO Preliminary Environmental Requirements and Estimates" JPL-D-20241.

Appropriate block, functional, or alternative mode redundancy shall be employed to avoid single-point mission critical failures. Specific exceptions to this requirement shall be identified and evaluated; they will be approved only if the failure mechanism is found to be acceptably improbable.

A mission-critical failure is defined to be a failure that results in the permanent loss of data from more than one scientific instrument during the mapping phase, loss of the relay capability during the relay phase, the failure to achieve and maintain the proper orbit or pointing control to within specified tolerances, the loss of science-critical engineering telemetry required for attitude determination, or the failure to achieve the quarantine orbit (if required) prior to the end of the mission.

The design shall also accommodate mission operation in degraded modes. A degraded mode of operation is defined to be one in which the primary scientific objectives of the mission can still be met, but at the expense of a loss of some scientific data and/or an increase in the complexity of the mission operations.

2.1.4.1 FAILURE MODES, EFFECTS, & CRITICALITY ANALYSIS (FMECA) –ORBITER AND INSTRUMENTS

The main objective of a FMECA is to identify success-critical Single Failure Points (SFPs). The FMECAs shall be performed and documented to analyze postulated failures and identify the potential resultant effects. FMECAs shall be performed at both the system level and at the orbiter subsystem level.

Interface FMECAs shall be performed at all subsystem, instrument, and GSE interfaces and anywhere block or functional redundancy is employed. As a minimum, these shall:

a. Consider all operational modes.
b. Be performed at the subsystem level interfaces to the piece part level to verify that a failure in any interface circuit cannot propagate to and/or damage the interfacing circuit and or damage hardware in another fault containment region.
c. Consider all parts that could be reasonably expected to produce an anomalous condition at the interface that would not otherwise be addressed (e.g., a DC-DC converter, internal to the assembly, that does not have over-voltage protection)
d. Verify that a failure in a non-critical circuit (e.g., telemetry, current monitoring) will not affect the performance of a critical function in a non-redundant circuit.
e. Verify that failures in ground support or test equipment (including power lines) cannot propagate to and damage the flight hardware.

2.1.4.2 FAULT TREE ANALYSIS (FTA) – ORBITER (RECOMMENDED FOR INSTRUMENTS)

FTA shall be performed at the mission system level. This analysis shall specify an undesired state of the system and then the system shall be analyzed in context of its environment and operation to find all credible ways in which the undesired event can occur.

FTAs shall also be performed on all mechanisms and devices. These mechanical FTAs shall address failure modes capable of occurring down to the lowest level piece part.

These analyses shall include an assessment of preventive measures to reduce failure likelihood and alternate modes of operation for mitigating failure effects. The corrective actions may be documented using guidelines in JPL D-5703, or contractor equivalent. The results of these analyses will enable engineering decisions to be made by the cognizant design organization to indicate whether or not additional analysis, testing, inspection, or other steps should be taken to increase the reliability of the flight hardware. These decisions shall be reported at all design reviews subsequent to completing the analysis.

2.1.4.3 WORST CASE ANALYSIS (WCA) – ORBITER (RECOMMENDED FOR INSTRUMENTS)

WCA shall be performed and documented on orbiter circuits. This analysis shall demonstrate that sufficient operating margin exists for all operating conditions when the individual circuits are subjected to any combination of the following:

a. WCA of electronics shall use part case temperatures of -20° to +85° C. (Based upon the temperatures defined in the environmental requirements document. In addition, if the board level thermal analysis indicates a temperature rise of more than 35°C from the thermal control surface (TCS) to the part case, then the WCA must be amended to include the additional temperature increase.)
b. Piece part manufacturing tolerance.
c. Part aging and drift for the operating life of the mission, plus one year expected ground test time.
d. Special factors such as shock, vibration, or vacuum where such conditions would contribute to variations in the circuit parameters.
e. Voltage, frequency, and load tolerances.
f. Effects of radiation (as defined in JPL D-20241).

The analysis shall be a true worst case in that the value for each of the variable parameters shall be set to limits that drive the output to a maximum (or minimum). The results of the analysis shall describe all deficiencies and performance restrictions that were identified.

2.1.4.4 POWER SUPPLY TRANSIENT ANALYSIS – ORBITER (RECOMMENDED FOR INSTRUMENTS)

A Power Supply Transient analysis shall be performed to determine the effects on the power system of all power converters using orbiter power. The analysis shall verify compliance with all applicable electrical system and EMC requirements for the following:

a. Transient performance
   - Inrush surge current at subsystem turn-on
   - Surge current due to mode changes
   - Conducted electrical noise generation delivered to input power lines
b. Power demand
   - Power consumption
c. Overload protection circuits
   - Fuses: operating margin
   - Current limiters: protection capabilities, limit level, duration
     - Grounding configuration compliance

2.1.4.5 ELECTRONIC PARTS STRESS ANALYSIS (E-PSA) – ORBITER AND INSTRUMENTS

Parts Stress Analysis shall be performed and documented to verify that the applied stress on each piece part does not exceed the de-rating values established in JPL D-8545, or approved equivalent. All analyses shall be documented on JPL-provided or approved forms. Contractors may use their own forms with JPL reliability and cognizant technical manager approval. The stress analysis shall use the proto-flight test temperature + 20°C (or proto-flight test temperature + temperature rise from piece part thermal analysis if available). The PSA shall be reviewed once the results of the piece part thermal analysis become available. This review shall insure that the assumed temperature rise envelops the predicated temperature rise and no part is overstressed.

2.1.4.6 THERMAL STRESS ANALYSIS – ORBITER AND INSTRUMENTS

Thermal stress analysis shall address the effect of the thermal environment, including worst case estimates, for all anticipated environmental conditions. The analysis shall address material fatigue and the effect of thermal cycling on solder joints, conformal coating, other critical materials, and semiconductor junction temperatures.

2.1.4.7 STRUCTURAL STRESS ANALYSIS – ORBITER AND INSTRUMENTS

Structural stress analysis shall be performed on mechanical and electromechanical subsystems/assemblies. The analysis shall address the effects to be experienced by the structure due to the dynamic environment (i.e., acceleration, shock, vibration, and acoustic noise), including worst case estimates for design environmental conditions. The analysis shall also address material fatigue.

2.1.4.8 SINGLE EVENT EFFECTS ANALYSIS (SEE) – ORBITER AND INSTRUMENTS

Circuit designs containing SEE sensitive parts shall be analyzed to minimize the effect of SEE and to assure compliance with system/subsystem level requirements. Performance requirements for operation during SEE are as follows:

a. Temporary loss of function or loss of data shall be permitted provided that the loss does not compromise subsystem/instrument health, full performance can be recovered rapidly, and there is no time in the mission that the loss is mission critical.
b. Normal operation and function shall be restored via internal correction methods without external intervention in the event of a Single Event Upset (SEU).
c. Fault tractability shall be provided in the telemetry stream to the greatest extent practical for all anomalies involving SEEs.
d. Irreversible actions shall not be permitted. The flight hardware shall have no parts that may experience unrecoverable radiation induced latch-up or gate rupture.

2.1.4.9 RELIABILITY BLOCK DIAGRAMS, RISK ASSESSMENT, QUANTITATIVE STATISTICAL ANALYSIS FOR TRADES - ORBITER

Reliability Block Diagrams, Probabilistic Risk Assessment (PRA), & Quantitative Statistical Analysis for Trades shall be used for relative trade studies in support of Mission Fault Trees, System Level FMECAs and mission and hardware design decisions. PRA shall be performed to determine technical areas of relatively high risk to the MRO mission. All areas identified shall be evaluated to determine additional assurance activities and/or alternate design approaches which could mitigate risk.

2.1.5 Reliability Development Requirements

2.1.5.1 MINIMUM OPERATING TIME REQUIREMENTS – ORBITER AND INSTRUMENTS

Orbiter electronics assemblies shall accumulate at least 300 hours of operation prior to integration into the orbiter (the last 100 hours to be failure free). At the orbiter system level, prior to launch, each single-string electronic assembly shall have at least 1000 hours operating time and each side of a block redundant element shall have at least 500 hours operating time

Instruments shall accumulate at least 400 hours of operation prior to integration into the orbiter (the last 100 hours to be failure free). After integration into the orbiter, instruments will accumulate at least an additional 200 hours prior to launch.

2.1.5.2 LIFE TEST – ORBITER AND INSTRUMENTS

Life testing is required for all life limited mechanical/electromechanical hardware. Specific requirements shall be documented to include:

- The number of cycles, including the predicated sum of ground plus in-flight cycles.
- Environments representative of in-flight conditions.
- Actual loads in-flight vs during life test.

2.1.5.3 PROTECTIVE AND REDUNDANT DEVICES/CIRCUITRY TESTING - ORBITER

Protective and redundant devices/circuitry internal to a block redundant or single string subsystem/component are often not identifiable as operable during normal subsystem/system testing. These devices/circuits shall be evaluated as follows:

a. Identify each protective/redundant circuit or device by circuit/subassembly designation.
b. Using this identification, perform a FMECA to identify piece part level failure modes whose occurrence would not be identifiable during normal testing.
c. Validate internal redundancy or protective functionality at the last possible test in normal subsystem and system test flow.
d. Verify that failures do not propagate to disable primary or redundant hardware

2.1.6 Support Equipment – Orbiter and Instruments

The level of reliability typically required for flight hardware is not warranted for support equipment (SE). SE that connects to flight units for test or evaluation shall be analyzed for compatibility with the hardware. Particular care and attention shall be directed at providing assurance that any failure experienced in the SE does not result in degradation or damage to the flight hardware. As a minimum, the following shall support the SE design and use:

a. Protective adapters.
b. Over-voltage protection for power source
c. FMEAs to be performed on the SE hardware interface to verify that a failure in the SE will not propagate across the interface and cause degradation or damage to the hardware under test.
d. Problem Failure Reports

2.1.7 Problem/Failure – Anomaly Reporting – Orbiter and Instruments

A closed-loop problem/failure reporting system is required and shall be implemented for flight hardware and software (when operating with flight hardware), critical ground support equipment (GSE), and for the mission operations phase. This reporting system shall also be used for engineering model hardware if there is any projected transfer of status to flight or flight spare hardware or if the engineering model is mated to flight hardware. Instruments or Contractors may use the on-line JPL anomaly reporting system, if appropriate, as documented in JPL D-8091, JPL Standard for Anomaly Resolution, Rev 2, or may use a JPL reviewed and approved equivalent meeting the intent of that document. All problems, failures, and anomalies shall be initially reported to JPL within one working day of occurrence and be made available for entering into the MRO problem/failure/anomaly database. All significant and Red-Flag PFRs shall be entered into the JPL PFR system. Updates and closure reports shall be provided as they occur.

Problem/Failure Reports (PFR) shall be written for orbiter flight hardware at the first application of power at the board level and for instruments at the first application of power at the instrument level.

All reported problems, failures, anomalies shall have a preliminary, approved risk rating within 10 days after occurrence using the standard JPL risk rating system (Table 2-1, and described in JPL D-8091) or an approved equivalent. Risk ratings of 1, 1 are approved/closed by the Cognizant Engineer and next level instrument management or designee, with MRO Mission Assurance Manager concurrence on the risk rating. Risk ratings of other than 1, 1 shall have closure approval by the MRO Mission Assurance Manager. Red Flag and Significant (high risk) ratings shall be approved by the MRO Project Manager and shall be transferred to JPL's PFR system. JPL D-8091 shall be used for JPL supplied flight hardware and is applicable for anomaly report risk rating definitions and requirements.

Table 2-1. Problem/Failure Risk Rating System

Failure Effect & Rating (Ignoring Redundancy)			Failure Cause/Corrective Action & Rating
Negligible (see definitions in D-8091)	1	1	Known Cause/Certainty in Corrective Action No known residual adverse effect, and/or no possibility of recurrence.
Significant (see definitions in D8091)	2	2	Unknown Cause/Certainty in Corrective Action No known residual adverse effect, and/or no possibility of recurrence.
Major or Catastrophic (see definitions in D8091)	3	3	Known Cause/Uncertainty in Corrective Action Some known residual adverse effect, and/or some known possibility of recurrence.
		4	Unknown Cause/Uncertainty in Corrective Action Some known residual adverse effect, and/or some known possibility of recurrence.
Red Flag Problem/Failure Reports Require Project Manager Approval			

2.1.8 Lessons Learned

The Project shall review NASA Lessons Learned (LLIS) & MCO/MPL Failure Lessons Learned and report on these issues at design reviews.

2.2 ENVIRONMENTAL ASSURANCE

2.2.1 Environmental Assurance

Environmental testing provides a basis for quality judgments to be made of flight hardware design and acceptability. The environmental test program consists of protoflight (PF) tests at the assembly/subsystem and the flight system levels. Analysis in lieu of tests may be performed for environments which are known to significantly degrade flight hardware or in cases where analyses are significantly more cost effective than tests and it is judged that there is negligible risk incurred by not performing a test.

Subsystems and assemblies designated for environmental tests and analyses shall be identified in the MRO Environmental Test and Analysis Requirements matrix in the contractor MRO Environmental Requirements document (ERD).

The program for environmental compatibility is interrelated with the design program. Specifications, procedures, reports, etc., are required to insure a consistent and properly oriented protoflight and acceptance program. The remainder of this Section is devoted to a further explanation of some of the items on the matrix and a discussion of basic program policies.

2.2.1.1 PROTOFLIGHT (PF) TESTS

Protoflight tests serve to simultaneously fulfill the requirements of qualification and acceptance of flight hardware where dedicated qualification units do not exist. Protoflight environmental testing demonstrates design adequacy and flight hardware readiness, including appropriate performance and margin tests (ref MRO Preliminary Environmental Requirements and Estimates document). To satisfactorily pass a protoflight environmental test, the equipment shall operate during and after environmental testing in accordance with the respective functional and performance requirements.

2.2.1.2 PROTOFLIGHT TESTS ARE THE NOMINAL STANDARD ENVIRONMENTAL TEST SET FOR ALL FLIGHT HARDWARE ENVIRONMENTAL COMPATIBILITY ANALYSIS

As previously stated, analysis in lieu of tests may be performed for environments which are known to significantly degrade flight hardware or in cases where analyses are significantly more cost effective than tests and it is judged that there is negligible risk incurred by not performing a test.

The environmental design requirements to be specified in the MRO contractor Environmental Requirements document provide the criteria against which such analyses will be performed. Those subsystems for which analysis is required in order to demonstrate satisfactory confidence for performance in the various mission environments are identified in the Environmental Test and Analysis Requirements matrix in the Environmental Requirements document.

An analysis report shall be prepared by the hardware cognizant engineer for each required analysis that appears in the Environmental Test and Analysis Requirements matrix. The report prepared by the cognizant hardware engineer is to be approved by a designated peer reviewer and by a Project designated reviewer. The report provides the Project with a summary of the analysis approach and the significant results, as well as a formal approval of the analysis. Since analysis results may affect hardware design, all reports for a given hardware item, as listed in the Environmental Test and Analysis Requirements matrix, shall be submitted to the Project Office prior to the beginning of PF environmental testing.

2.2.2 Test Of Flight Spare Hardware

Flight spare hardware shall satisfy the following criteria:

- If originally an inherited qualification unit: the hardware shall be reviewed upon completion of engineering testing to determine the need for refurbishment prior to commitment of the hardware for use as flight spare hardware.
- If a new build: the hardware shall be subjected to appropriate flight acceptance testing.

2.2.3 Environmental Design Requirements

Orbiter environmental design requirements are to be contained in the MRO Environmental Requirements document. Instrument environmental design requirements are derived from the MRO contractor Environmental Requirements

2.2.4 Selection Of Environmental Tests

The assembly and system (orbiter or instrument) level environmental test programs are determined by an evaluation of the various environments having significant environmental interactions with the orbiter. The environmental tests selected at both the system and assembly levels are those which tend to yield the maximum information about the flight worthiness of the equipment.

Nominally, assembly level environmental tests will consist of the following protoflight level tests:

- random vibration (force limited recommended)
- thermal vacuum
- EMC: radiated and conducted emissions and susceptibility, plus isolation
- Pyroshock will be evaluated on a case by case basis
- Acoustics will be evaluated on a case by case basis
- Thermal cycling will be evaluated on a case by case basis

Nominally, system level environmental tests will consist of the following protoflight level tests:

- random vibration (force limited to 200 Hz)
- acoustics
- EMC: radiated susceptibility and emissions
- Thermal vacuum/balance
- Pyroshock

The orbiter-bus contractor/partner shall prepare an environmental test and analysis matrix from the assembly level up to the orbiter system level.

2.2.5 Assembly Level Environmental Test Implementation Policies

Formal environmental tests shall be performed on all hardware intended for flight, including spares, at the lowest practical assembly level as defined in the Environmental Test and Analysis Requirements matrices. For any given assembly which is flying more than one unit on the orbiter or has a flight spare, the environmental tests shall be conducted in the same test setup configuration and modes of operation. This consistency of environmental testing shall also be applied to environmental tests on hardware configurations qualified in previous environmental test programs. If needed, magnetic acceptance tests (other than characterization tests) shall be performed after completion of all other environmental tests and prior to delivery for orbiter integration.

Flight hardware will operate in logic and power states during the protoflight tests which validate the integrity of all electrical interfaces and circuits. This includes circuits internal to the unit and those which directly connect to other portions of the orbiter. Assemblies which are powered during the launch phase shall operate within specification during dynamic tests. Anomalous behavior shall be documented on a Problem/Failure Report (P/FR). All assemblies shall demonstrate normal operation after completion of dynamics testing.

2.2.6 System Level Environmental Testing

All orbiter subsystem and system level environmental testing shall be conducted in accordance with the subsystem and system environmental test plans as approved by the MRO Project.

2.2.7 Environmental Test Specifications

Environmental Test Specifications shall be prepared by the flight hardware providing organization to define the environmental test levels and durations for assembly/subsystem, instrument, and system level environmental testing.

An Environmental Test Authorization and Summary (ETAS) form (attached) shall be prepared by the flight hardware cognizant engineer and approved by the MRO Environmental Requirements Engineer for all JPL tested flight hardware. The summary will identify the set of environmental tests required for the flight unit. The orbiter contractor and non-JPL instrument providers are not required to prepare an ETAS for its own or its vendor supplied flight hardware, but shall document the required environmental tests, levels and durations for each assembly and report the details of the results.

2.2.8 Test And Analysis Configuration

All flight hardware including spares shall be grouped for testing at the assembly level in the configuration identical with the flight configuration. In all tests, the electrical cabling, connectors, and other fittings normally associated with the assembly or the system, shall be used and shall be considered as part of the test article. The same configuration shall be used for protoflight, flight acceptance, and workmanship environmental testing.

The hardware cognizant engineer and the JPL Quality Assurance representative shall verify that the hardware is configured in the test facility as specified in the ETAS or Procedure prior to the performance of assembly level environmental testing of that hardware.

Configuration of the orbiter for system level testing shall be as near flight as possible. Configuration compromises may be necessary because of the size of the orbiter and facility limitations. Preparation of the orbiter for the system level testing shall be in accordance with the applicable test plan.

The orbiter procedures will ensure that all of the electrical circuits and interfaces between all subsystems and instruments are adequately exercised to validate their proper function.

2.2.9 Environmental Test Procedures

The operation of environmental test equipment and facilities during the performance of environmental tests of flight hardware shall be accomplished in accordance with approved test procedures. The cognizant testing agency shall prepare the Environmental Test Procedure.

The procedures shall be re-evaluated in the event of test facility malfunction or failure or if a revision is made to the ETAS or test approval document. Re-approval of the procedure is required if the specification change results in a formal revision.

2.2.10 Assembly Level Test Authorization

For JPL provided flight hardware, approval of environmental testing for flight hardware is obtained through an ETAS. For orbiter bus assemblies, the orbiter contractor will determine the approval process, with JPL insight and concurrence. For instrument flight hardware, the instrument provider will determine the approval process, with JPL insight and concurrence.

2.2.11 Environmental Test Standards

Any agency that performs environmental testing must do so in accordance with certain minimum standards, whether these facilities are at JPL, at a contractor's or instrument provider's facility or at an independent test laboratory. These minimum standards are defined in Standard Environmental Testing Facilities and Practices document (900-434). Test facility conformance to this Standard will be reviewed and evaluated by the MRO Project Office. The applicable test standards for EMC tests are given in MIL-STD-462.

2.2.12 Environmental Test Documentation, Precedence And Control

2.2.12.1 ENVIRONMENTAL TEST AUTHORIZATION AND SUMMARY (ETAS) – JPL SUPPLIED FLIGHT HARDWARE

An approved ETAS takes precedence over requirements specified in other environmental documents. Changes and exceptions to environmental requirements which are noted on the ETAS and are approved by the ERE do not require a supporting ECR or Waiver. If further changes to any requirements are necessary after an approved ETAS has been obtained, the revisions, together with any appropriate rationale or justification, shall be submitted for approval to the ERE prior to beginning of any test.

2.2.13 Environmental Test Reporting

After each assembly, subsystem or system environmental test is terminated (whether because the test requirements were successfully completed or because a test failure has occurred) the testing agency shall prepare a Test Agency Report. The Test Agency Report will specifically address any deviations from the approved test procedure.

For each serial number of each hardware group subjected to each assembly level environmental test, a report shall be made by the hardware cognizant engineer on the ETAS (for JPL) or orbiter contractor or instrument provider equivalent. This report shall be available for Project review and as inputs to the assembly Delivery and Pre Shipment Review Boards.

2.2.14 Protoflight Test Article Identification

Each protoflight assembly shall be subjected to the entire PF test program given in the Environmental Test and Analysis Requirements matrix.

If approved by the MRO Project, an engineering model of an assembly may be used as a qualification unit and be subjected to qualification/protoflight environmental testing. The engineering model must be flight-like and shall be manufactured using the same assembly techniques and fabrication processes as the flight hardware including: structure, thermal design, shielding, cabling, circuit layout, power consumption, functional modes, and electrical parts with the same signal characteristics. Engineering models to be exposed to dynamic or thermal vacuum environments shall have their electronics conformally coated.

An engineering model meeting the criteria described above will be under formal configuration control and the formal P/FR process. Protoflight testing of the first flight unit may still be required.

2.2.15 Failure During Test

Any failure or malfunction of an instrument or orbiter assembly during an environmental test or any failure or malfunction of an environmental test facility that would affect an environmental test shall be cause for the immediate issuance (less than 24 hours) of a Problem/Failure Report, or contractor/instrument provider equivalent, in accordance with the approved MRO problem/failure reporting requirements. Failure or malfunction of an instrument or orbiter assembly during environmental testing shall be interpreted as a test failure. The test shall be immediately reviewed for consideration of discontinuance unless continuation is of diagnostic value and will not result in damage to the assembly. An assembly-level environmental test shall not be interrupted because of problems or failures associated with the test hardware if the hardware cognizant engineer and the test engineer agree that the test should be continued. The Spacecraft System Manager or his designee shall determine whether to interrupt a system level test in the event of a failure or malfunction of the orbiter. In the event of test article or environmental simulation hardware problems or failures, or deviations of test conditions from the specified limits, P/FRs shall be prepared immediately.

If there is a facility failure, two P/FRs are required – one against the facility and one against the flight hardware under test. The facility P/FR requires the facility personnel to assess the test hardware and implement corrective actions for subsequent testing. The flight hardware P/FR requires the cognizant engineer to assess the effects of the facility failure on his hardware.

If a test article failure occurs during environmental test, after implementation of the corrective action the failed item must be retested though the point at which the failure occurred.

2.2.16 Pass/Fail Determination

Test article failure or malfunction during an environmental test will be considered as a test failure. A P/FR shall be written for all out-of-specification or anomalous conditions in accordance with the MRO problem/failure reporting and analysis requirements.

All test related P/FRs for a specific environment must be listed on the ETAS forms, if in use, and submitted within 3 days of test termination (whether or not the testing was completed). The probable disposition of P/FRs must be known prior to determination of whether or not a test has been passed or failed.

After consideration of any and all redesign, modifications, or reworks open against the hardware, the cognizant engineer will present his pass/fail position for Project concurrence. This process should all be completed prior to acceptance for integration into the orbiter.

2.2.17 Retest Requirements

Environmental retests of assemblies are performed to:

- complete the protoflight or flight acceptance testing of hardware that has failed during its environmental test program,
- requalify flight hardware design where design changes, modifications or configuration changes occur after completion of environmental testing,
- verify the flight worthiness of refurbished units as flight spares, and
- verify the flight acceptibility of workmanship performed as part of rework not covered by items 1 to 3.

Failures of flight hardware resulting from assembly level environmental testing shall, in general, invalidate the protoflight or flight acceptance test program for that assembly. Retesting to prescribed environments shall be required after the cause of the failure is corrected.

Any design change, modification, or configuration change occurring after completion of the environmental testing shall, in general, invalidate the environmental test program and, depending uon the nature of the change, be the cause for retesting under certain selected environments. Any design change or modification occurring after protoflight testing shall require an assessment by the cognizant engineer and Project to determine if reiteration of the protoflight testing is required.

The retest requirements will be documented on an approved retest ETAS or test procedure. Table 5.1.1 describes the general guidelines to be used for determining retest requirements.

Flight hardware may not be retested without a reapproval of the updated ETAS or test approval documentation.

JPL

ENVIRONMENTAL TEST AUTHORIZATION AND SUMMARY (ETAS)

AUTHORIZATION SECTION

PROJECT		LOG NO.	
SUBSYSTEM / ASSEMBLY TITLE			DATE ISSUED
REFERENCE DESIGNATION NO.	PART NO. (IF MULTIPLE, ATTACH LIST)	REV.	SERIAL NO.
HARDWARE TYPE ☐ EM QUAL ☐ FLIGHT ☐ FLIGHT SPARE ☐ OTHER ______	PRE-ENVIRONMENTAL INSPECTION REPORT NUMBER (ATTACH IR)		
WIRING HARNESS ☐ FLIGHT ☐ FLIGHT SPARE ☐ EM ☐ S.E.	PART NO.	REV.	SERIAL NO.
TEST DESCRIPTION (CHECK ALL APPLICABLE) ☐ SINE VIBRATION ☐ PYROSHOCK ☐ ACOUSTIC ☐ EMC ☐ OTHER ______ ☐ RANDOM VIBRATION ☐ THERMAL VAC ☐ THERMAL ATMOSPHERE		TYPE OF TEST ☐ QUALIFICATION ☐ FLIGHT ACCEPTANCE ☐ PROTO FLIGHT ☐ RETEST	
WILL ALL TESTS/LEVELS/DURATIONS REQUIRED BY THE PROJECT DOCUMENTS BE PERFORMED ON THIS UNIT? ☐ YES ☐ NO (IF NO, ATTACH EXCEPTIONS LIST) ENTER PROJ. DOC. NO. AND REV. ______			
HAS THE UNIT PASSED ALL PRE-ENVIRONMENTAL FUNCTIONAL TESTS? ☐ YES ☐ NO (IF NO, ATTACH EXPLANATION)	BRIEF EXPLANATION		
HAVE ALL DESIGN ANALYSES BEEN COMPLETED AND REQUIRED CHANGES BEEN IMPLEMENTED? ☐ YES ☐ NO (IF NO, ATTACH EXPLANATION)	BRIEF EXPLANATION		
IS THE TEST ARTICLE IDENTICAL TO OTHER FLIGHT UNITS? ☐ YES ☐ NO (IF NO, LIST DIFFERENCES AND ATTACH)	BRIEF EXPLANATION		
ARE ALL PFRs AGAINST THIS UNIT CLOSED? ☐ YES ☐ NO (IF NO, WILL ANY OPEN PFRs AFFECT ENVIRONMENTAL TESTING? HOW?)	BRIEF EXPLANATION		
HAVE ALL WAIVERS AND ECRs BEEN APPROVED AND ARE THEY INCORPORATED? ☐ YES ☐ NO (IF NO, ATTACH EXPLANATION) ☐ N/A	BRIEF EXPLANATION		

TEST AUTHORIZED BY

COGNIZANT ENG. DATE	TECHNICAL MGR./INSTR MGR./PI REP. DATE	ENVIRONMENTAL REQUIREMENTS ENG. DATE

SUMMARY SECTION

TEST AGENCY (IF MULTIPLE, ATTACH SUMMARY AND TEST DATES)	TEST INITIATION DATE	ACCUMULATED OPERATING HOURS PRIOR TO FIRST ENVIRONMENTAL TEST
SERIAL NUMBERS ACTUALLY TESTED	TEST TERMINATION DATE	OPERATING HOURS DURING ENVIRONMENTAL EXPOSURE

TEST DESCRIPTION

VIBRATION	ACOUSTIC	PYROTECHNIC SHOCK	☐ THERMAL VACUUM	☐ TEMPERATURE ATMOSPHERE	☐ OTHER
AXES: X Y Z		AXES: X Y Z			
SINE VIBRATION ☐ ☐ ☐	☐	☐ ☐ ☐	PRESSURE:		
RANDOM VIBRATION ☐ ☐ ☐		SHOCKS/AXIS:	NO. OF CYCLES:	NO. OF CYCLES:	______

EMC	☐ COND. SUSC.	☐ COND. EMIS.	☐ ISOLATION	TEMP. LEVEL (°C) AND ACCUMULATED DURATION (HRS.) HOT: ____°C, ____h COLD: ____°C, ____h
☐ ESD	☐ RAD. SUSC.	☐ RAD. EMIS.	☐ MAGNETICS	HOT: ____°C, ____h COLD: ____°C, ____h

WERE THERE ANY PFRs GENERATED DURING ENVIRONMENTAL TESTS? ☐ YES ☐ NO (IF YES, ATTACH A COPY OF THE PFRs)	LIST PFR NOS. / BRIEF EXPLANATION
ARE THE POST ENVIRONMENTAL DAMAGE INSPECTIONS COMPLETE? ☐ YES ☐ NO (IF YES, ATTACH A COPY OF THE INSPECTION REPORTS. IF NO, ATTACH EXPLANATION.)	BRIEF EXPLANATION
WERE ALL PLANNED TESTS/LEVELS/DURATIONS ACHIEVED? ☐ YES ☐ NO (IF NO, ATTACH EXPLANATION)	BRIEF EXPLANATION

☐ TESTS HAVE NOT BEEN SUCCESSFULLY COMPLETED. SEE THE ATTACHED SUMMARY FOR ACTIONS THAT NEED TO BE TAKEN.

COGNIZANT ENG. DATE	TECHNICAL MGR./INSTR MGR./PI REP. DATE	ENVIRONMENTAL REQUIREMENTS ENG. DATE

☐ HARDWARE HAS SUCCESSFULLY COMPLETED THE ENVIRONMENTAL TESTS LISTED ON THIS FORM OR REMAINING ACTIONS HAVE BEEN TAKEN, INCLUDING RETEST.

COGNIZANT ENG. DATE	TECHNICAL MGR./INSTR MGR./PI REP. DATE	ENVIRONMENTAL REQUIREMENTS ENG. DATE

PAGE 1 JPL 2683 R 1/98 FF

.

Table 2-2. Environmental Retest Guideline Matrix

Flight Equipment Refurbishment Categories	General Restest Guidelines – Protoflight Hardware*			
	Vibration	**Thermal**	**Magnetics**	**Electrical Isolation**
CATEGORY I – Significant hardware replacements and design changes	Complete PF Retest – All Environments			
CATEGORY II – Hardware replacements and design updates	Random 3-axes PF level PF duration	PF levels PF duration	PF or FA characterization	FA characterization
CATEGORY III – Electronic piece part change-outs in assembly locations with difficult accessibility (i.e., major dismantling). No design change.	Random 3-axes FA level FA duration	If previous temperature problems observed: PF levels and durations <u>Otherwise</u>: FA levels and durations	FA characterization	FA characterization
CATEGORY IV – Electronic piece part change-outs with direct accessibility in common location.	Random ≤3-axes FA level FA duration	FA levels and durations	FA characterization	FA characterization if changeout in end circuits or in temperature sensor circuits
CATEGORY V – Electronic piece part change-out (single part), easy access, simple rework with skilled technician. QA witness.	Random To be negotiated	FA levels Durations to be negotiated	FA characterization	FA characterization if changeout in end circuits or in temperature sensor circuits

SECTION 3
ELECTRONICS PARTS ENGINEERING

3.1 APPLICABILITY

The electronic parts requirements specified herein are applicable to all flight hardware. This includes all JPL, contractor, subcontractor and other supporting organizations providing flight equipment. In cases of conflict between this document and any applicable document, this document shall take precedence.

3.2 SYSTEM CONTRACTORS

All contractors and sub-contractors shall meet the requirements of this document unless an approved waiver has been signed by the MRO Project Office. Electronic Parts Project Implementation Plans must be submitted to the MRO Project for approval. The JPL Parts Project Manager shall review and disposition all contractor submitted Parts Plans.

3.3 PARTS REQUIREMENTS

3.3.1 Standard Parts

Standard parts are those parts which meet both the Parts Reliability Requirements and the Radiation Effects Requirements of this section.

3.3.1.1 PART RELIABILITY REQUIREMENTS

All packaged parts shall meet the minimum parts levels as specified below. Level 1 parts should be used whenever feasible.

For orbiter level single-string applications, the minimum requirements are as follows :

- NPSL Level 1
- MIL-PRF-38534 Class K, QML-38534
- MIL-PRF-38535 Class V, QML-38535, (MIL-M-38510,Class S)
- MIL-PRF-19500 JANS, QPL-19500
- Military Established Reliability (ER) passive devices, Failure Rate Level S

For non-mission critical instruments, or redundant systems, the minimum requirements are as follows :

- NPSL Level 2, **with upgrade**
- MIL-PRF-38534 Class K, QML-38534 (Level 1)
- MIL-PRF-38535 Class Q, QML-38535, (MIL-M-38510,Class B) **with upgrade** (Level 2)
- MIL-PRF-19500 JANTXV, QPL-19500, **with upgrade** (Level 2)
- Military Established Reliability (ER) passive devices, Failure Rate Level R (Level 2)

Upgrade for Level 2 parts shall consist, as a minimum, of the following:

a. X-ray
b. Parts Impact Noise Detection (PIND), for cavity devices
c. Crystal Oscillators will have additional screening requirements per CS515574, Rev. E

Note : Destructive Physical Analysis (DPA) are required on all Level 2 part lots, as specified below.

3.3.1.1.1 Custom Hybrid, MCM and HDI Microcircuits

Hybrid devices designed and fabricated by non-QML sources, such as JPL or their non-QPL contractors, shall be in conformance with requirements of Class H reliability level of MIL-PRF-38534 with a 10 piece element evaluation for each die device type. Pre-cap visual inspection and document review(e.g. element evaluation, burn-in data and rework travellers) prior to seal is required for all hybrids.

Substrates used for custom hybrids (as defined above) shall be subjected to additional screening to include:

100% Screening Requirements for Substrates including samples used for qualification

Test	Method	Condition	Quantity
Temperature Cycling	1010	E, 10 cycles@-65^{0}C to 300^{0}C.	100%
Electrical testing		Per schematic	100%
*Acoustic Microscopy	JEDEC Std-035	All internal features meet specified substrate design requirements	100%
Radiographic	2012	All internal features meet specified substrate design requirements	100%

*Most Acoustic Microscopy techniques require a medium, such as de-ionized water, to propagate the sound waves that surrounds the substrate. If moisture is a concern, perform this test as a qualification.

Qualification Requirements for Substrates on at least a sample of 2 substrates

Test	Method	Condition	Quantity
Cross-section*	Defined by the Hybrid Specialist		2(0)
High temperature aging with additional adhesion testing	Defined by the Hybrid Specialist		2(0)

*Perform sufficient cross-sections and inspect under high magnification to verify all internal features meet specified substrate design requirements

The Hybrid Parts Specialist shall identify in-process inspection points that ensure adequate yield per project needs and will be called out in the travelers and inspected by QA.

All parts shall be reviewed, evaluated, and where necessary, tested for characterization , against the system (project) radiation requirements. These requirements may consist of tolerance to Total Ionizing Dose (TID) and/or single event effects (SEE), such as single event upset (SEU), single event burnout (SEB), single event gate rupture (SEGR), or single event latch-up (SEL).

3.3.1.2 RADIATION REQUIREMENTS

3.3.1.2.1 Total Ionizing Dose (TID)

All flight parts are expected to operate within post-irradiation specification limits following exposure to twice (2x) the expected total dose environment. The TID radiation environment includes all radiation components : X-rays, gamma rays, protons, electrons, neutrons and heavy ions.

3.3.1.2.2 Dose Rates

All linear bipolar Integrated Circuits (IC's) shall be lot tested both at 50 rad(Si)/s and 0.005 rad(Si)/s to three times (3x) the expected TID environment (without RDM). An alternate form of this dose rate testing may be used if approved by the JPL Parts Project Manager (PPM). Enhanced low dose rate (ELDR) effects shall be evaluated and results reported to JPL PPM to assure that parametric degradation due to ELDR have been accounted for worst case analysis. Other device types shall be tested in accordance with MIL-STD-883, Method 1019.4, or per recommended test methodology found in JPL D-18002, Radiation Test Requirements for Ionization and Displacement Damage, or JPL-approved contractor equivalent.

3.3.1.2.3 Displacement Damage

All parts shall be evaluated for displacement damage sensitivity. Potentially susceptible parts include but are not limited to optical devices, photo-detectors, charge-coupled devices, optocouplers, LEDs, laser diodes and precision bipolar linear devices.

3.3.1.2.4 Single Event Latchup (SEL)

All CMOS devices (including those with epitaxial layers) shall be subject to latchup evaluation. Most bipolar, SOS, SOI and DI (Dielectrically Isolated) devices need not be evaluated. All parts shall exhibit no latchup up to LET of 75 MeV-cm^2/mg and a fluence of 10^7 ions/cm^2. The beam angle shall not exceed 60 degrees and test ions shall have a range greater than 35 microns. Bias shall be at specified maximum voltage. Tests shall be performed at room ambient and at elevated temperature of 125°C or the maximum specified operating temperature of the part.

3.3.1.2.5 Single Event Upset (SEU)

All microcircuits containing bistable elements (e.g. flip-flops, counters, RAMs, microprocessors, etc.) shall be characterized so that an upset rate calculation can be performed. A sufficient number of data points (a minimum of four) shall be taken to determine the curve of device cross section versus LET (to saturation or to an LET of 75 MeV-cm^2/mg, whichever comes first).

The requirements for parts SEU acceptability are:

a. No upsets during SEU testing to above specifications , or

b. Verification of device bit error rate of 10^{-10} per day or better in the galactic cosmic ray environment, or
c. Meets the requirements for the overall subsystem upset rate requirement.

Note that the requirements for ”no observed upsets” or “upset rate = 1 upset/year/device” does not imply that the rate is sufficiently low to ensure compliance with the upset requirements imposed at the instrument or functional level.

3.3.1.2.6 Single Event Burnout (SEB)

All power transistors operated in the off-mode may be susceptible to, and shall be evaluated for single event gate rupture (SEGR) at the lowest applicable V_{GS}. The survival voltage (V_{DS} for MOSFETs and V_{CE} for bipolars) shall be established from exposure to a minimum fluence of 10^6 ions/cm² of an ion with a minimum LET of 37 MeV-cm^2/mg and with a range greater than 35 microns. The application voltage shall be derated to 75% of the established survival voltage. Test requirements for single event burnout are similar to those for SEGR except that the drain current (or collector current for bipolar transistor) must be measured to determine if burnout occurs. Testing shall be performed with normal beam incidence and at room ambient temperature.

- Drain voltage rating ≤100 V — Ion range 35 µm or more
- Drain voltage rating between 100 and 250 V — Ion range 40 µm or more
- Drain voltage rating above 250 V — Ion range 80 µm or more

3.3.1.2.7 Single Event Gate Rupture (SEGR)

All power MOSFETs operated in the off-mode may be susceptible to and shall be evaluated for SEGR at the worst case VGS conditions. The survival voltage VDS shall be established from exposure to a minimum fluence of 10^6 ions/cm² of an ion with a minimum LET of 37 MeV/mg/cm^2 and with a range greater than 35 microns. The application voltage shall be derated to 75% of the established survival voltage. Testing shall be performed with normal beam incidence and at room ambient temperature.

- Drain voltage rating ≤100 V — Ion range 35 µm or more
- Drain voltage rating between 100 and 250 V — Ion range 40 µm or more
- Drain voltage rating above 250 V — Ion range 80 µm or more

3.3.1.2.8 Single Event Transient (SET)

All linears, mixed-signal devices, optocouplers, and GaAs devices shall be evaluated for susceptibility to SETs with heavy ions.

3.3.1.3 NON-STANDARD PARTS APPROVAL

Any electronic parts that do not meet the definition of Standard Part, as defined above, are considered non-standard parts. Design organizations intending to use non-standard parts must submit a Non-Standard Parts Approval Request (NSPAR). Non-standard parts may only be used if the NSPAR is approved by the implementing organization. JPL maintains the right to revoke approval when reviewing monthly reports (provided by the implementing organization) on the status and disposition of the NSPARs.

3.3.1.4 PARTS LIST REVIEWS

All electronic parts lists shall be submitted to JPL for review and approval. The parts lists will be in hardcopy, as well as electronic format.

A Preliminary Parts List must be submitted, 2 months after contract start. Monthly updates to the Preliminary Parts List are to be provided, highlighting deltas to the previously submitted parts list.

An As-Designed Parts List must be submitted 1 month prior to the Critical Design Review (CDR).

3.3.2 Parts Acquisition

3.3.2.1 HERITAGE PARTS

Residual inventory (i.e., heritage parts), in this context, refers to parts previously approved and procured for prior flight Project applications. Residual electronic parts may be used for MRO only if they meet all requirements of this document.

3.3.2.2 PARTS PROCUREMENT

Purchase orders shall not take exception to reference specifications or requirements therein unless approved by the JPL MRO Parts Project Manager or via waiver.

3.3.2.3 CUSTOMER SOURCE INSPECTION

Pre-seal visual inspection shall be performed on all packaged flight ASICs, hybrid microcircuits, Multi-chip Modules (MCMs), crystal oscillators, and nonstandard relays.

3.3.2.4 RADIATION LOT ACCEPTANCE TESTING (RLAT)

Device types that are known or shown to be marginal by a TID characterization test or analysis, if still requested for use in flight equipment, shall be subjected to RLAT. The RLAT specifications and requirements shall be reviewed and approved by the Project cognizant engineer(s), JPL's Parts Project Manager and Parts Radiation Specialist, prior to start of testing. Radiation related TID testing and evaluations shall be done in accordance with MIL-STD-883, Method 1019.4, or per recommended test methodology found in JPL D-18002, Radiation Test Requirements for Ionization and Displacement Damage, or JPL-approved contractor equivalent. Other radiation related testing, if required, shall be performed as described in Radiation Effects Requirements of this section. All CMOS devices shall be subjected to RLAT for SEL per the SEL requirements of this section, unless there is evidence of lot specific test data, manufacturer's certification and/or the wafers were produced at foundries with QML or process controlled lines.

3.3.2.5 DESTRUCTIVE PHYSICAL ANALYSIS (DPA)

Grade-2/Class-B (Level 2) packaged electronic parts require DPA per SSQ25000. DPAs shall also be performed on a sample of each manufacturing lot date code for all crystal oscillators, filters, ceramic capacitors (except MIL-C-123), relays, MIL-C-39010 inductors, and all nonstandard packaged parts (including multi-chip modules and hybrids), regardless of procurement to Grade-1/Class S/Class K (Level 1) levels. MIL-C-39010 inductors/transformers shall be sectioned to examine the adequacy of the termination. Relays shall have an internal visual examination. Chip capacitors and resistor networks require a DPA. The results of the DPA shall be evaluated by the procuring activity, and the lot shall be accepted or rejected based on the criteria of the specification.

3.3.3 Electronic Parts Application

3.3.3.1 PARTS DERATING

Each part used in flight equipment shall be applied in a manner such that the temperatures experienced and electrical stresses produced when it is operating do not exceed the derating criteria defined in JPL D-8545 "JPL Derating Guidelines", or JPL-approved contractor equivalent.

3.3.3.2 ELECTROSTATIC DISCHARGE (ESD) CONTROL

ESD damage or degradation may occur in static-sensitive electronic parts during handling of the parts from procurement through incoming inspection, testing, screening, storing and final assembly/test. To protect static-sensitive parts from ESD, handling of parts shall be controlled by the requirements of JPL D-1348 "JPL Standard for Electrostatic Discharge Control", or JPL-approved contractor equivalent.

3.3.3.3 NASA AND GOVERNMENT INDUSTRY DATA EXCHANGE PROGRAM (GIDEP) ALERTS

All hardware-delivering design agencies, both internal and external to JPL, are responsible for reviewing all Alerts, and for immediately reporting corrective action for applicable Alerts (i.e. for parts used in the hardware) to the project. The design agency shall present a report at the CDR, and another at the Pre-Ship Review, that lists all of the Alerts that are pertinent to the parts used in the flight design, the possible impact should the part fail, and the actions proposed and those taken. It is the responsibility of the design agency to avoid the use of defective parts in flight equipment.

3.3.3.4 PARTS FAILURE ANALYSIS

Failure analysis is required for all part failures that occur subsequent to part-level screening. The only exception to this is for parts that are damaged by human error (e.g., improper installation). Analysis shall be carried to the point that lot dependency of the failure mode can be determined. Failure Analysis reports shall be written to document the analysis approach, the determined failure mode and mechanism (i.e., cause) responsible for the failure, and the corrective actions required to prevent recurrence of the failure. If a lot dependency is found, the JPL Mission Assurance Manager (MAM) will disposition the assemblies using the suspect lot.

3.3.3.5 AS-BUILT PARTS LIST

An As-Built Parts List shall be released prior to hardware integration and test. In addition to the information required in the Preliminary Parts Lists, the As-Built Parts List shall include for each different part the actual part marking, part number purchased, manufacturer, lot date code, serial number (for serialized parts), wafer and wafer lot numbers (when required), parts test lot numbers (where applicable), procurement specification number, traceability number (when assigned by the cognizant parts organization), the serial number and part number of the next assembly level into which the part is installed (e.g., board or module), and the reference designator of the location where each part is used on the next assembly level. The as-built parts list shall be supplied to the JPL Parts Project Manager in a computer-readable format.

SECTION 4
MATERIALS & PROCESSES

4.1 REQUIREMENTS

4.1.1 Selection of Materials and Processes

All materials and processes shall be qualified for the application in which they are used. Issues of flight qualification are very application specific and shall be reviewed on a case-by-case basis. In the event that a designer does not have appropriate data to indicate the suitability of a material or process, the MRO M&P Engineer and the Hardware Responsible Engineer shall generate a qualification/ evaluation plan.

4.1.2 Standard Materials and Processes Selection

JPL Document STD-00009 and MSFC-HDBK-527/JSC 09604 are recommended as sources for material selection data. The listing of a material in JPL Document STD-00009 or MSFC-HDBK-527/JSC 09604 does not mandate blanket approval for all applications. The use of a listed material or process may be additionally restricted due to molecular or particulate contamination, magnetic properties, radiation susceptibility, electrostatic discharge properties electromagnetic interference and other environmental or operations requirements. The particular application for each material shall be reviewed and approved by the JPL MRO M&P Engineer.

4.1.3 Submittal of Material Identification and Usage Lists

Material Identification and Usage Lists for materials and processes used for applications including structural members, mechanical parts, packaging, cabling, and fasteners shall be submitted by all Hardware Responsible Engineers (JPL, contractors, and suppliers). These forms, or JPL-approved equivalent contractor forms, shall be filled out and submitted for approval by the JPL MRO M&P Engineer. Preliminary MIULs should be submitted to the JPL MRO M&P Engineer as soon as practicable in the design and engineering processes and in accordance with contractual requirements established by JPL and its contractors. Submittal of MIULs should occur one month prior to the Preliminary Design Review and one month prior to the Critical Design Review (CDR). Any open or unresolved issues are to be identified at the PDRs and CDRs. Subsequent to the CDRs, MIULs shall be updated as required and submitted as soon as practicable to the JPL MRO M&P Engineer for review and approval. In the case of design changes, the design agency shall submit the changes to the JPL MRO M&P Engineer for approval.

4.1.4 Classification of MIUL Submittals

The JPL MRO M&P Engineer will classify the submittals according to the following criteria. The classification given to a material or process shall be based on the acceptability of the material or process, application and controlling documentation. The criteria are: Class 1 – Acceptable; Class 2 – Qualified Acceptable; Class 3 – Provisional; Class 4 – Unacceptable.

4.1.5 Materials Usage Agreements (MUA)

Material Usage Agreement (MUA) forms shall be prepared by all MRO Hardware Responsible Engineers for applications of materials and processes that do not meet the requirements specified in this document. For JPL designed hardware, MUAs shall be submitted to the JPL MRO M&P Engineer for approval. For non-JPL designed hardware, MUAs shall be prepared for review and approval of the contractor M&P Engineer. All contractor approved MUAs shall then be submitted to the JPL MRO M&P Engineer for final approval. If approval is not granted and use is still desired, a waiver request shall be submitted per MRO Project Configuration Management Plan. The requirement for submittal of waivers is applicable to both JPL and contractors.

4.2 MATERIALS AND PROCESSES REVIEW

4.2.1 Evaluation

Materials and Processes shall be assessed by the combined consideration of three factors: 1) Material and Process type, including manufacturer, 2) Specific design, application or requirement, and 3) documented control provisions.

4.2.2 Thermal Vacuum Stability and Outgassing

Material thermal vacuum stability and outgassing behavior shall be compatible with the mission environment and shall not adversely affect mission performance. Materials shall meet the requirements of JSC-SP-R-0022A. Only those organic materials with a total mass loss (TML) that does not exceed 1.00 percent and a collected volatile condensable mass (CVCM) that does not exceed 0.10 percent, when tested in accordance with ASTM E595 or contractor equivalent procedures, shall be considered for use.

Some materials that meet JSC-SP-R-0022A may not be satisfactory, particularly in areas that are extremely sensitive to contamination. In such instances, special treatments, such as prolonged thermal-vacuum bakeouts, shall be employed to ensure that material outgassing will not adversely affect MRO mission performance. Such thermal-vacuum bakeout procedures shall be developed with and have the approval of the Project Contamination Control Engineer.

4.2.3 Flammable Materials

Materials shall be non-combustible or self-extinguishing to the greatest extent possible and conform to the flammability requirements of NASA-STD-6001. Rationale for use of and acceptability of flammable materials in amounts over 454 grams (1 pound) or where the longest dimension is greater than 30.5 cm (12 inches) shall be submitted in a MUA. Where flammable materials must be used, the standard hazard elimination and control requirements apply, as follows: (a) two failure tolerance on ignition sources, (b) physical separation of the flammable material from ignition sources, and (c) elimination of flame propagation paths.

4.2.4 Galvanic Corrosion

In applications where dissimilar metals will be in intimate contact, the metals shall be compatible with regard to galvanic corrosion to the greatest extend possible. Methods to minimize the potential for galvanic corrosion shall be implemented. MIL-STD-889 shall be used as a guideline for controlling dissimilar metal contacts.

4.2.5 Stress Corrosion Cracking

The use of A or B rated materials per MSFC-HDBK-527/JSC-09604, or Table I and II materials per MSFC-SPEC-522, is acceptable. The materials listed in Table III, or "C" rated, should be considered for use only in applications where it can be demonstrated conclusively that the probability of stress corrosion is remote. If Table III or "C" rated materials or materials not listed in MSFC-SPEC-522 or MSFC-HDBK-527/JSC-09604 are to be used, a stress corrosion form shall be submitted to the JPL MRO M&P Engineer for approval.

4.2.6 Welding

All welding operators on automatic, semi-automatic, or manual welding shall be qualified accordance with MIL-STD-1595 or a qualification procedure approved by the MRO Materials Engineer. Weld rod or wire used as a filler metal on structural parts shall be fully certified and documented for composition, type, heat number, manufacturer, and supplied to provide traceability to the end use item. All fracture critical welds shall be non-destructively inspected per the requirements of NASA-STD-5003.

4.2.7 Non-Destructive Inspection

Non-Destructive Evaluation (NDE) shall be conducted on highly stressed and mission or safety critical items. Non-destructive inspection (NDI) techniques shall meet the requirements of MIL-I-6870 (or contractor equivalent) for magnetic particle, radiographic, eddy current, and ultrasonic inspection. Dye penetrant inspection shall meet the requirements of ASTM E1417 (or contractor equivalent). Etching of 0.0002 to 0.0004 inches prior to inspection is required. Specifications shall be reviewed by the JPL MRO M&P Engineer.

4.2.8 Shelf-Life Limited Life Materials

All materials with shelf-life sensitivity shall be used within their shelf-life limits. Extending the shelf-life of a material shall require the prior approval of the JPL MRO M&P Engineer.

4.2.9 Radiation Resistance

Materials used for MRO flight hardware shall be able to withstand the radiation environment specified in the MRO Environmental Requirements Document with less than twenty percent degradation in their applicable properties. In applications where the estimated radiation dosage exceeds the twenty percent degradation level or is greater than the available test data, shielding shall be used. In assessing materials for space environmental resistance, the effects of vacuum ultraviolet, ultraviolet, gamma ray, electron and proton radiation shall be considered. In cases where there are no available data, testing may be required

4.2.10 Electrical Arc-Tracking Resistance

Electrical wire insulation, wire accessories and materials in contact with electrical circuitry shall not be capable of arc-tracking due to electrical discharges. The use of materials that are susceptible to arc-tracking shall be documented in a MUA. If their use can not be avoided, care shall be taken in the handling of the material to minimize the possibility of arc-tracking. In such cases, the amount of power shall also be limited.

4.2.11 Hazardous Materials

All materials that are exposed to toxic or hazardous fluids shall be evaluated for compatibility with that fluid in their intended application. All materials that are exposed to a hazardous fluid shall be rated compatible per MSFC-HDBK-527/JSC-09604. Materials rated “A” are acceptable, while those rated “B” shall be batch tested.

4.2.12 Magnetic Materials

The use of magnetic materials shall be limited, as necessary, to meet orbiter or instrument magnetic requirements.

4.2.13 Static Charge Sensitivity

Materials shall be evaluated to determine if their Electrostatic Discharge (ESD) characteristics are compatible with project requirements per JPL D-1348.

4.2.14 Fungi

Flight hardware shall be designed so that materials are not nutrients for fungi except when used in permanent hermetically sealed assemblies and other accepted and qualified parts. Other necessary fungi nutrient material applications shall require treatment by a method which will render the resulting exposed surface fungi resistant. The criteria for the determination of fungi and moisture resistance shall be those contained in MIL-STD-810.

4.2.15 Design Allowables for Structural Parts

Statistically based material design allowables shall be used for structural analysis of MRO flight hardware to the greatest extent possible. MIL-HDBK-5 and MIL-HDBK-17 are primary sources of statistically based material property data. A-basis allowables shall be used for pressure vessels and for all metallic structures. A-basis allowables shall also be used for structures where failure of a single load path would result in loss of structural integrity. Use of B-basis allowables shall require JPL MRO M&P approval for redundant structures. If a different protocol for design allowables is followed, a justification shall be presented to the MRO M&P Engineer.

4.2.16 Fasteners

Fasteners used in the MRO Project shall be selected based on the criteria contained in SPI-4-11-8. Fasteners shall be selected from the JPL Preferred Fastener List (PFL) to the greatest extent possible. Where fasteners are used in critical applications, JPL Process Specification FS 511316, Detail Specifications for Qualification of Critical Fasteners, shall be followed. The JPL Fastener Specialist shall approve all fastener selections.

4.2.17 Materials

Externally threaded fasteners shall be fabricated from materials that have a high resistance to Stress Corrosion Cracking (SCC). Materials that have moderate or low resistance to SCC are not acceptable for use for fasteners.

4.2.18 Materials for Fracture Critical Fasteners

Fracture critical fasteners shall not be fabricated from materials which have low fracture toughness. (A material is considered to have low fracture toughness if the ratio of fracture toughness to tensile yield strength, KIC/Fty is less than 1.66 mm1/2 (0.33 in1/2)). Fracture critical fasteners shall not be fabricated from Ti-6Al-4V.

4.2.19 Fastener Traceability

All externally threaded fasteners used for flight applications shall be certified. Fasteners used in structural applications shall have critical certification, requiring documentation of chemical and physical test results traceable to both heat and lot numbers, as described in SPI 4-11-8. Fasteners used in non-structural applications shall have, as a minimum, a certificate of conformance.

4.2.19.1 MATERIAL TRACEABILITY

Traceability of all materials incorporated into flight hardware shall be maintained. Records of material manufacturer, date of manufacturer, batch and lot identification numbers, applicable materials and process specifications, expiration date, and purchase order numbers shall be recorded. For the acceptance and traceability of flight bulk materials, including materials received on spools, in bottles, cans or kits, Quality Assurance Procedure QAP 44.10, Receiving Inspection and Identification of Flight Bulk Materials, shall be followed.

4.2.19.2 LUBRICANTS

It shall be the responsibility of each organization, JPL and contractors, providing flight hardware that incorporates lubricants to prevent contamination of that hardware and critical adjacent hardware, i.e., mirrors, lenses, other experiments, etc., by outgassing of the lubricant or by lubricant creep or the natural wetting and wicking tendencies of the lubricants. Graphite or lubricants with significant amounts of graphite are abrasive in vacuum and shall not be used for flight hardware.

SECTION 5
CONTAMINATION CONTROL

5.1 GENERAL

Contamination Control Requirements are derived from Orbiter and Instruments requirements. These governing Project Requirements for contamination control are not limited to instrument functional requirements, optical performance degradation requirements, thermal surface properties requirements, planetary protection requirements, safety/reliability requirements, etc. The following General Deliverable Hardware Contamination Requirements are delineated in the contamination requirement implementation plans such as Project Contamination Control Plan, ORBITER Contamination Control Plan and Instrument Contamination Control Plan and can be superceded by the Specific Hardware Contamination Control Requirements.

5.2 ASSIGNMENT OF RESPONSIBILITY

It is the responsibility of the hardware supplier to deliver hardware capable of meeting all of the Contamination Control Requirements whether at hardware acceptance or at I&T. The hardware supplier is also responsible for the decontamination performance for hardware designed to have such capability.

5.3 DOCUMENTATION REQUIREMENTS

The hardware supplier is required to supply necessary certified contamination control compliance documents prior to the hardware acceptance.

5.4 ACCEPTANCE REQUIREMENTS

Hardware that met the general hardware contamination requirements and specific requirements shall be deemed acceptable by Contamination Control.

5.5 GENERAL DELIVERABLE HARDWARE CONTAMINATION REQUIREMENTS

5.5.1 Design Requirements

No entrapped ullage shall be permitted with the exception of hermetically sealed ullages. Exposed adhesive lines shall not have direct view of any optics. Venting shall be from a more stringent area to a lesser stringent area. Any potential for vent impingement shall be noted and its impact assessed by responsible contamination engineer.

5.5.2 Material Requirements

All the materials used shall be space qualified, shall not shed particles and shall have the following outgassing characteristics: 1) less than 1 percent total mass loss (TML) and less than 0.1 percent collected volatile condensable mass (CVCM) per ASTM method E-595. 2) Additional outgassing requirements specified in the Specific Hardware Contamination Control

Requirements. All of the adhesives, mold release agents and lubricants used for the hardware shall be submitted to the contamination and materials engineer for approval prior to the use.

5.5.3 Cleaning Requirements

All the hardware shall be cleaned to the required levels prior to vacuum outgassing measurement. All of the hardware surfaces with the exception of optics shall be capable of withstanding isopropyl and ethanol alcohol cleaning. The hardware supplier is also required to recommend at least one type of cleaning solvent for the deliverable hardware. All of the hardware surfaces with the exception of optics shall be capable of withstanding Hepa vacuum brushing.

5.5.4 Surface Cleanliness Requirements

All optical components and associated hardware shall be delivered with surface cleanliness at MIL-STD 1246C level 150A or better while all other components shall be delivered with surface cleanliness at MIL-STD 1246C level of 300A or better.

5.5.5 Outgassing Requirements

All the hardware delivered shall pass the outgassing requirement delineated in the Specific Hardware Contamination Control Requirement and the molecular outgassing from the hardware at its maximum operating temperature plus 10 +/-2°C in a vacuum not exceeding a rate of 1 x 10-7 g/cm2 hour. This will be measured by a temperature-controlled quartz crystal microbalance (TQCM) operating at 10 +/-2°C below the coolest sensitive surface temperature. The hardware shall be certified at measured outgassing rate and should places in an appropriate clean container immediately after the measurement test. Exposing hardware to uncontrolled environment after measure can invalidate the outgassing certification. Hardware thermal vacuum bakeout shall be used to achieve the desired outgassing rate.

5.5.6 Protective Covers & Storage Containers

Clean removable cover(s) shall be provided for hardware with potential for accumulating environmental contamination fallout. Clean containers shall be provided for the transportation and storage of deliverable hardware. The cleanliness of cover and container surfaces facing the hardware shall be at same level as the hardware itself.

5.5.7 Facility Requirements

Hardware manufactured in areas exceeding ISO-14644-1 Class ISO 8 environment should undergo proper cleaning before assembly. Any assembly excluding optics shall be made in an ISO-14644-1 Class ISO 8 or better environment. Final preparation of the optical assemblies should occur in an ISO-14644-1 Class ISO 7 or better environment. An ISO-14644-1 Class ISO 5 or better environment with vertical down-flow tent or clean bench should be used for installing the optical elements and open optical assemblies.

5.5.8 Contamination Non-Entrapment Requirements

The hardware shall not entrap contaminants at any stage of the hardware buildup.

5.5.9 Variance from Requirements

Variance from contamination requirements can be made: 1) by substituting with comparable requirements. 2) by an assessment that concludes the variance's impact to the governing Project Requirements is acceptable.

5.6 SPECIFIC HARDWARE CONTAMINATION CONTROL REQUIREMENT

In addition to meeting the General Deliverable Hardware Contamination Control Requirements, a deliverable hardware must meet its specific contamination control requirement(s) delineated in the appropriate Contamination Control Plan(s).

SECTION 6
HARDWARE QUALITY ASSURANCE

This section defines the detailed hardware quality assurance requirements for contractors, vendors, and external suppliers supporting on the MRO Project. Changes to this plan require the approval of the MRO project management.

6.1 QUALITY MANAGEMENT SYSTEM

All prime contractors and sub-tier contractors shall be ISO 9001 certified or have an equivalent Quality Management System.

It is the responsibility of the prime contractor to flow down JPL requirements to sub-tier vendors and to ensure that sub-tier vendors supporting the MRO Project produce hardware and services that meet JPL requirements. The prime contractor is responsible for the qualifying their sub-tiers prior to contract award and for the monitoring and quality of parts produced by sub-tier vendors.

The prime contractor shall designate at least one person as the manager or lead dedicated to the MRO Project, representing the contractor's Quality Assurance (QA) organization. This person is responsible for providing an MRO-specific QA and inspection plan that governs the methods of implementing QA on the MRO Project; QA direction to those in the company supporting MRO; and for ensuring the quality of parts and services provided by sub-tier vendors. This QA manager/lead is also responsible for communicating status, concerns, and problems to the JPL MRO Project Quality Assurance representative.

The prime contractor is responsible for providing to the JPL QA representative access to appropriate areas of the facility, a desk, and computer for resident assignment. Notification of meetings, reviews, testing, test set-ups, inspection points, and other activities that require JPL involvement shall be given to the JPL representative in advance. Based on the manufacturing flow plan and the inspection flow provided by the contractor QA manager/lead, the assigned JPL QA representative will determine inspection points that require JPL QA to witness or verify. The contractor shall provide to the JPL QA a minimum of three working days notice for such itinerant source inspections.

6.2 CRITICAL PROCESSES

In addition to having a robust Quality Management System, contractors must be able to demonstrate capabilities in critical processes that affect the quality of the parts or hardware being built. Contractors' capabilities can be demonstrated using various methods including metrics and process control charts. Critical processes are identified as those which affect the functionality, performance, or quality of the hardware and that failure to control these processes will result in significant risk to the end item. Critical processes include but are not limited to the following:

a. Plating
b. Anodizing
c. Heat treating

d. Welding
e. Soldering
f. Polymeric applications
g. Cleaning
h. Die attachment
i. Wire bonding
j. Magnetic Particle inspection
k. Radiographic inspection
l. Ultrasonic inspection
m. Liquid penetrant inspection

All processes used such as Electro-Static Discharge control plan, workmanship standards, contamination control shall be qualified in accordance with NASA, JPL requirements, or contractors' equivalent specifications.

6.3 TRAINING

Contractors are responsible for providing adequate training and certification to personnel and for ensuring sub-tier contractors are qualified in the aforementioned critical processes as well as electro-static discharge, critical hardware handling, and transporting critical hardware, contamination control, etc as it pertains to the assignment.

6.4 QUALITY RECORDS AND CONTROLLED DOCUMENTS

Contractors are required to retain quality records and furnish them to the MRO Project. Quality records are those records which furnish objective evidence of activities performed or results achieved relating to the fabrication, assembly, integration and test of parts/hardware. Quality records include manufacturing planning records detailing specific steps performed, and inspection points; test logs and/or test documents detailing the test set up (temperature setting, dwell time, etc), test duration, and results achieved; records documenting nonconformances and the respective dispositions; corrective action records; calibration records; parts list for configuration management; and engineering and specification changes. Full traceability must be maintained on all JPL hardware designated as flight, flight spare, engineering model, ground support equipment and other critical equipment that interfaces with flight hardware.

Controlled documents include test procedures, drawings, manuals, specifications, and other written documentation relating to the design, development, manufacture, and test of the hardware. Contractors are required to maintain and store controlled documents that pertain to the design, development, manufacture, and test of JPL hardware.

6.5 NON-CONFORMANCE REPORTING

Contractors shall have an effective closed loop reporting system for the handling of non-conformances with a means to measure the effectiveness of the corrective actions taken.

Non-conformances that impact the performance, function, or fit up of the part or any that require non-standard critical repairs are to be elevated to the Material Review Board level, requiring JPL MRO Project visibility and approval. Similarly, Material Review board activities occurring at the sub-tiers require JPL approval.

6.6 HANDLING, PACKAGING, SHIPPING, AND STORAGE CONTROLS

The contractors will have effective and established processes for the handling, packaging, shipping, and storage of critical hardware. All precautions should be taken in the to preclude the introduction of contamination to JPL hardware, damage to hardware due to improper packaging or electro-static discharge, and co-mingling of acceptable and unacceptable parts. Flight hardware, flight spare, engineering model, ground support equipment and other critical equipment that interface with flight hardware will be handled as Critical Hardware.

Non-conforming hardware shall be kept in areas only designated for non-conforming hardware with precautions made to prevent the co-mingling of these parts with other acceptable hardware.

SECTION 7
SOFTWARE QUALITY ASSURANCE

7.1 INTRODUCTION

7.1.1 Scope

This Section 7.1 provides the SQA Plan for the MRO Software (S/W) development organizations including the JPL, contractors, vendors, and industrial partners. The SQA requirements for the contractors, vendors, and, industrial partners are described in Sections 7.2. The JPL SQA Requirements are included in Section 7.3.

7.1.2 Purpose

The purpose of SQA is to achieve the highest quality-to-cost ratio within the Project's constraints and policies, and to increase the probability of overall mission success. A series of rigorous SQA activities will be performed on the Project throughout the S/W life cycle to assure that the S/W development will comply with the pre-defined quality processes, and all the S/W product quality will meet or exceed the Project requirements.

7.1.3 Responsibilities

Each S/W Development Organization shall designate the qualified SQA Engineer (SQAE) to perform the required SQA activities described in this SQA Plan. The SQAE shall provide feedback to the Project and S/W Development Team for each SQA activity.

7.2 CONTRACTOR SQA REQUIREMENTS

7.2.1 S/W Development Process

Contractor SQAE shall assist the Project in tailoring the S/W development process, within the constraints of cost and schedule, and with acceptable risks. Contractor SQAE shall verify that the S/W development process will comply to the JPL Software Development Process Description (D-15378) and the JPL Design, Verification/Validation and Operations Principles for Flight Systems (D-17868), and identify the deviations (if any) from the D-15378 and D-17868.

Contractor SQAE shall assure that S/W classification will be established, and the processes and standards as specified in the S/W Management Plan (SMP) will be followed by the S/W Development Team.

7.2.2 S/W Requirements Trace

Contractor SQAE shall verify that following two-way requirement traces will be established to assure the completeness and correctness of S/W traceability:

a. System/Subsystem Interface Requirements and S/W Requirements
b. S/W Requirements and S/W Design/Implementation

c. S/W Requirements and S/W Acceptance Tests

7.2.3 S/W Safety/Hazard/Fault Analysis

Contractor SQAE shall assure that the S/W System Safety/Hazard/Fault Analysis will be performed on the safety-critical S/W and mission critical S/W. The recommended techniques for the S/W System Safety/Hazard/Fault Analysis include:

a. S/W Fault Tree Analysis (SFTA)
b. S/W Failure Modes Effect and Criticality Analysis (SFMECA)

Contractor SQAE shall assure the S/W safety in the following manner:

a. It will not produce output values and/or timing that place the system in a hazardous state
b. It will not fail to recognize or handle H/W failures that it's required to control or respond to

7.2.4 S/W Reviews

Contractor SQAE shall participate in all the S/W related reviews to the extent possible to assure adequacy, consistency and completeness of MRO Project Review Plan, standards/guidelines, S/W requirements, design, code, and test plan/procedures/results.

Contractor SQAE shall assure that the action items/defects resulting from the S/W reviews will be tracked and resolved, before entering the next development phase.

Contractor SQAE shall participate in and support the delivery manager in ensuring that all S/W deliverables as specified in the SMP, CDRLs, and DRDs will be verified and validated, prior to any S/W delivery review or S/W Review/Certification Requirement review (SRCR) review.

7.2.5 S/W Verification and Validation (V&V)

Contractor SQAE shall assure that the S/W V&V process will have adequate end-to-end S/W testing coverage from flights to ground data system.

Contractor SQAE shall analyze the test objectives and assure that entry and exit criteria for each level of testing will be properly defined.

Contractor SQAE shall assure that the S/W Acceptance Test will cover the following:

a. Traceability Matrix exists between S/W requirements and Test Cases.
b. Stress testing is adequate.
c. Reuse S/W is tested in the Project's operating environment.
d. Fault Protection functions are adequately tested, including failure modes that are identified by SFTA and SFMECA.

All the following items of the S/W and firmware destined for Qualification Protoflight, Flight, Flight Spares, shall be subjected to Contractor SQA evaluations:

a. Accuracy of as-built product identification
b. Proper Test Plan/Procedures/Reports have been released

c. Installation Manuel
d. S/W Requirements are properly traced in a test traceability matrix or equivalent
e. List of open/closed PFR or liens against this delivery

7.2.6 Problem/Failure Reporting (PFR) and Tracking

Contractor SQAE shall assure that the problems/failures found during S/W developmental test and integration test with H/W will be reported and tracked to closure.

Contractor SQAE shall assess the criticality of S/W related PFRs, evaluate the risks associated with their disposition, and track the proper PFR closure.

7.2.7 S/W Metrics Collection and Analysis

Contractor SQAE shall assist in metrics definition and acquisition to assure that processes are being monitored for effectiveness and accuracy.

7.2.8 S/W Configuration Management (CM)

Contractor SQAE shall assist in defining and assessing the S/W CM plan and procedures.

Contractor SQAE shall assure that S/W CM will be performed through the identification, control, audit, and status accounting of configuration items which represent the S/W at each life cycle phase of development.

7.2.9 S/W Engineering Change Request (ECR)

Contractor SQAE shall participate in assessing the impacts of S/W related ECRs.

Contractor SQAE shall assure that the proper ECR will be implemented and verified.

7.3 JPL SQA REQUIREMENTS

7.3.1 S/W Risk Assessment

JPL SQAE shall periodically assess the Project S/W (including the Contractor S/W) development processes and products throughout the S/W life cycle to assure the S/W process/development issues are evaluated relative to end-user goals and requirements.

JPL SQAE shall complete the first S/W assessment by Project PDR, and recommend appropriate levels and mix of SQA and/or NASA IV&V Facility activities in support of the mitigation of risks associated with the Project S/W per JPL Project SQA Planning Policy (DMIE-44452). The level of NASA IV&V Facility support recommended for a project will be a risk-based decision that takes into account:

a. Risks to the mission success
b. Project resources (e.g. Project S/W development resources)
c. S/W safety hazards
d. JPL onsite capabilities

e. NASA IV&V Facility unique capabilities and resources
f. JPL S/W Quality Assurance capabilities and resources

A set of pre-defined criteria and checklist will be used to assess S/W development processes and products. The results of the assessment will contain a list of risk items with mitigation actions and activities.

7.3.2 Interaction with the S/W Contractor

JPL SQAE shall interact with the Contractor S/W Development Team and SQAE to assure the compliance of S/W development processes and the quality of S/W products:

a. Support the JPL Contract Technical Manager (CTM) or Cognizant Engineer in the preparation and evaluation of the Contract Proposals including Request for Proposal (RFP), Statement-Of-Work (SOW), Contract Data Requirement List (CDRL), and Data Requirement Description (DRD) to ensure appropriate quality provisions and clauses are defined, including the Contractor EIDP requirements
b. Provide insight/oversight (as applicable), monitoring and auditing of the Contractor SQA activities to assure compliance with the Project SQA requirements
c. Assess the Contractor S/W processes and products
d. Participate in the Contractor S/W Technical Reviews, Milestone Reviews, MMRs, and S/W Delivery Reviews.
e. Witness the Critical S/W Acceptance Tests
f. Generate the SRCR form to certify the acceptance of the delivered S/W products.
g. Report findings to the JPL Mission Assurance Organization and Project Management
h. Assure that Partners/Contractor/NASA Centers (P/C/N) will provide objective evidence (e.g. verification matrices, test records, reports, memos, meeting minutes, compliance matrix, etc.) to show that the Project SQA requirements are met. Assigned resident/itinerant SQAE shall support that complements P/C/N SQA function.

7.4 SQA REQUIREMENTS VS. S/W CLASSES

Each of the SQA requirements listed in this Section 7 is assigned to its applicable S/W class(es) as defined in the MRO SMP. Table 7.1 shows the SQA Requirements vs. S/W Classes as a crosscheck.

Table 7-1. MRO SQA Requirements vs. S/W Classes

Rqmnt ID	Software Quality Assurance (SQA) Requirements	S/W Classification		
		Class A	Class B	Class C
Contractor SQA Requirements				
S/W Development Process				
SQA-1.1	Contractor SQAE shall assist Project in tailoring the S/W development process, within the constraints of cost and schedule, and with acceptable risks.	X		
SQA-1.2	Contractor SQAE shall verify that the S/W development process will comply to the JPL Software Development Process Description (D-15378) and the JPL Design, Verification/Validation and Operations Principles for Flight Systems (D-17868), and identify the deviations (if any) from the D-15378 and D-17868.	X	X	
SQA-1.3	Contractor SQAE shall assure that S/W classification will be established, and the processes and standards as specified in the S/W Management Plan (SMP) will be followed by the S/W Development Team.	X	X	X
S/W Requirements Trace				
SQA-2	Contractor SQAE shall verify that following two-way requirement traces will be established to assure the completeness and correctness of S/W traceability: a. System/Subsystem Interface Requirements and S/W Requirements b. S/W Requirements and S/W Design/Implementation c. S/W Requirements and S/W Validation Tests	X	X	
S/W Safety/Hazard/Fault Analysis				
SQA-3.1	Contractor SQAE shall assure that the S/W System Safety/Hazard/Fault Analysis will be performed on the safety-critical S/W and mission critical S/W.	X		
SQA-3.2	Contractor SQAE shall assure the S/W safety in the following manner: a. It will not produce output values and/or timing that place the system in a hazardous state b. It will not fail to recognize or handle H/W failures that it's required to control or respond to	X		

Rqmnt ID	Software Quality Assurance (SQA) Requirements	S/W Classification		
		Class A	Class B	Class C
S/W Reviews				
SQA-4.1	Contractor SQAE shall participate in all the S/W related reviews to the extent possible to assure adequacy, consistency and completeness of MRO Project Review Plan, standards/guidelines, S/W requirements, design, code, and test plan/procedures/results.	X	X	
SQA-4.2	Contractor SQAE shall assure that the action items/defects resulting from the S/W reviews will be tracked and resolved, before entering the next development phase.	X	X	
SQA-4.3	Contractor SQAE shall participate in and support the delivery manager in ensuring that all S/W deliverables as specified in the SMP, CDRLs, and DRDs will be verified and validated, prior to any S/W delivery review or S/W Review/Certification Requirement review (SRCR) review.	X	X	X
S/W Verification and Validation (V&V)				
SQA-5.1	Contractor SQAE shall assure that the S/W V&V process will have adequate end-to-end S/W testing coverage from flights to ground data system.	X	X	
SQA-5.2	Contractor SQAE shall analyze the test objectives and assure that entry and exit criteria for each level of testing will be properly defined.	X		
SQA-5.3	Contractor SQAE shall assure that the S/W Acceptance Test will cover the following: a. Traceability Matrix exists between S/W requirements and Test Cases. b. Stress testing is adequate. c. Reuse S/W is tested in the Project's operating environment. d. Fault Protection functions are adequately tested, including failure modes that are identified by SFTA and SFMECA.	X		
SQA-5.4	All the following items of the S/W and firmware destined for Qualification Protoflight, Flight, Flight Spares, shall be subjected to Contractor SQA evaluations: a. Accuracy of as-built product identification b. Proper Test Plan/Procedures/Reports have been released c. Installation Manuel d. S/W Requirements are properly traced in a test traceability matrix or equivalent e. List of open/closed PFR or liens against this delivery	X	X	X

Rqmnt ID	Software Quality Assurance (SQA) Requirements	S/W Classification		
		Class A	Class B	Class C
Problem Reporting and Tracking				
SQA-6.1	Contractor SQAE shall assure that the problems/failures found during S/W developmental test and integration test with H/W will be reported and tracked to closure.	X	X	
SQA-6.2	Contractor SQAE shall assess the criticality of S/W related PFRs, evaluate the risks associated with their disposition, and track the proper PFR closure.	X		
S/W Metrics Collection and Analysis				
SQA-7	Contractor SQAE shall assist in metrics definition and acquisition to assure that processes are being monitored for effectiveness and accuracy.	X		
S/W Configuration Management (CM)				
SQA-8.1	Contractor SQAE shall assist in defining and assessing the S/W CM plan and procedures.	X		
SQA-8.2	Contractor SQAE shall assure that S/W CM will be performed through the identification, control, audit, and status accounting of configuration items which represent the S/W at each life cycle phase of development.	X	X	X
S/W Engineering Change Request (ECR)				
SQA-9.1	Contractor SQAE shall participate in assessing the impacts of S/W related ECRs.	X		
SQA-9.2	Contractor SQAE shall assure that the proper ECR will be implemented and verified.	X	X	
JPL SQA Requirements				
S/W Risk Assessment				
SQA-10.1	JPL SQAE shall periodically assess the Project S/W (including the Contractor S/W) development processes and products throughout the S/W life cycle to assure the S/W process/development issues are evaluated relative to end-user goals and requirements.	X	X	
SQA-10.2	JPL SQAE shall complete the first S/W assessment by Project PDR, and recommend appropriate levels and mix of SQA and/or NASA IV&V Facility activities in support of the mitigation of risks associated with the Project S/W per JPL Project SQA Planning Policy (DMIE-44452).	X	X	

Rqmnt ID	Software Quality Assurance (SQA) Requirements	S/W Classification		
		Class A	Class B	Class C
Interaction with the S/W Contractor				
SQA-11	JPL SQAE shall interact with Contractor S/W Development Team and SQAE to assure the compliance of S/W development processes and the quality of S/W products: a. Support the JPL Contract Technical Manager (CTM) or Cognizant Engineer in the preparation and evaluation of the Contract Proposals including Request for Proposal (RFP), Statement-Of-Work (SOW), Contract Data Requirement List (CDRL), and Data Requirement Description (DRD) to ensure appropriate quality provisions and clauses are defined, including the Contractor EIDP requirements b. Provide insight/oversight (as applicable), monitoring and auditing of the Contractor SQA activities to assure compliance with the Project SQA requirements c. Assess the Contractor S/W processes and products d. Participate in the Contractor S/W Technical Reviews, Milestone Reviews, MMRs, and S/W Delivery Reviews. e. Witness the Critical S/W Acceptance Tests f. Generate the SRCR form to certify the acceptance of the delivered S/W products. g. Report findings to the JPL Mission Assurance Organization and Project Management h. Assure that Partners/Contractor/NASA Centers (P/C/N) will provide objective evidence (e.g. verification matrices, test records, reports, memos, meeting minutes, compliance matrix, etc.) to show that the Project SQA requirements are met. Assigned resident/itinerant SQAE shall support that complements P/C/N SQA function.	X	X	

Legend: X- Required to be followed
Blank - Optional

SECTION 8
SYSTEM SAFETY

The MRO Project will follow the NASA safety strategy that “Mission Success Starts with Safety” to protect the public, NASA workforce, astronauts and pilots, and high-value equipment and property. The purpose of a Safety Program is to ensure risk to hardware and personnel is minimized through the life cycle of the Project.

8.1 OCCUPATIONAL SAFETY

All facilities in which flight hardware will be stored, fabricated, assembled, tested and integrated, will be monitored on a consistent basis to assure safe working practices and a safe working environment for JPL and contractor personnel. Industrial hygiene, electrical safety, fire and life safety, pressure systems safety, and construction safety will be the primary issues addressed from both the hazard abatement and remediation standpoint, as well as from the code compliance standpoint.

Formal and informal safety inspections of facilities, Facility Safety Surveys, Operations Safety Surveys, mishap reports, and formal training programs assure Contractor and JPL compliance with Cal/OSHA, NEC, NFPA, and UBC Codes, as well as specific contractual NASA requirements.

All buildings containing flight hardware will be monitored for industrial safety concerns including lifting and elevating equipment, fire suppression systems, pressure systems and components, life safety issues, building modifications, access and egress issues, evacuation procedures, emergency response, etc.

8.2 RANGE AND KSC SAFETY

The Air Force range safety group at Patrick Air Force Base requires that all equipment, flight hardware, and operations at Cape Canaveral Air Force Station (CCAFS) comply with EWR 127-1 “Eastern and Western Range Regulation– Range Safety.” Compliance with KHB 1710.2D, “Kennedy Space Center Safety Practice Handbook”, is also required, for orbiter where pre-launch servicing is performed at KSC. JPL, contractors, and instrument suppliers will comply with the requirements of both documents.

As required by EWR 127-1, a Missile System Pre-launch Safety Plan (MSPSP) will be prepared which describes the flight system, instruments and any potentially hazardous ground support equipment and operations. Hazards involved with the equipment and its use during pre-launch preparation of the flight hardware will be identified, as well as the methods by which the hazards will be eliminated, controlled, and verified. Air Force and KSC approval of required documents will be obtained prior to shipment of the orbiter and GSE to the launch sites.

8.3 SYSTEMS SAFETY

All F/S hardware, Science Instruments and support equipment will be designed and operated in a manner to ensure safety of both personnel and equipment during all phases of fabrication, test, and operations. This will be accomplished to the maximum degree practicable by assuring that the hardware design has the appropriate safety characteristics. Hazards that cannot be eliminated by design are dealt with by proper procedures, safeguards, operational techniques, training programs, monitoring, and alarm systems.

In order of descending significance, the following considerations will be addressed: (1) personnel safety, (2) flight critical equipment catastrophic damage, and (3) flight critical equipment degradation.

Project safety requirements will be documented in the Project Safety Plan (MRO 000-000), which will define the approach to be used and requirements to be met throughout all Project activities. Requirements for in-house efforts will be defined in accordance with the JPL Safety Policy and JPL Document D-560, “JPL Standard for Flight Systems Safety.” The Project Safety Plan will specify safety activities commensurate with the potential hazards, to either equipment or personnel, associated with the Flight System and Science Instruments. The Project Safety Plan will identify all Project organization responsibilities and authorities for performing safety functions both at JPL and at contractor facilities.

8.4 SCIENCE INSTRUMENTS:

Science instrument safety requirements will be met through the MRO Project Safety Plan, safety analysis, and safety support required by letter agreement for the acquisition of the science instruments. The Instrument Provider shall provide, as a minimum, all necessary data input for inclusion into the MSPSP including analysis for specific hazards that may be associated with the instrument.

SECTION 9
PLANETARY PROTECTION

The planetary protection requirements for a Mars orbiter are:

1. All flight hardware is to be assembled and maintained in class 100,000 clean rooms (or better), as measured in the operating mode.
2. The probability of an impact of Mars by any part of the launch vehicle (including the upper stage) that leaves Earth vicinity must not exceed 10^{-4}.
3. The probability of an impact of Mars by the orbiter due to all causes must not exceed:
   (a) .01 for the first 20 years after launch
   and (b) .05 for the succeeding 30 year period.
4. The Project must provide all necessary documentation, including an organics inventory (material list).